



NAVAL FACILITIES ENGINEERING SERVICE CENTER
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**DESCRIPTION AND REQUIREMENTS
FOR
CANDIDATE WATERFRONT
ENGINEERED WOOD
MATERIALS AND COMPONENTS**

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EXECUTIVE SUMMARY

This NFESC report is a part of the Engineered Wood Project, Phase One, headed by Washington State University and sponsored by the Office of Naval Research. The overall project objective is to develop high performance wood-based products and to integrate these products with existing Navy waterfront maintenance and construction systems. Phase One major objectives are:

1. *Materials Development*: Develop cost effective processing techniques to diversify existing wood/thermoplastic composites and integrate carbon-fiber reinforcement.
2. *Structural Design and Analysis*: Optimize the structural systems to guide design of the structural components.
3. *Recycling*: Investigate methods to clean and reuse creosote-treated piles.
4. *Demonstration Projects*: Demonstrate applications of commercial wood/thermoplastic composites as a replacement for current shore facility components.

This report identifies and describes areas where wood-based materials can be used to strengthen or replace existing waterfront components or structures. Coupled with these descriptions are requirements for these components, including materials specifications and critical properties as applicable, gleaned from military criteria documents. Military standards covered include mostly Military Handbooks and NAVFAC Guide Specifications. Pertinent Guide Specifications have been included as appendices. Physical and mechanical properties for commercially available engineered wood composites are included in Appendix A.

These waterfront component descriptions and requirements along with a consideration of commercially available wood-plastic composites design characteristics are used to develop a list of product opportunities of highest potential value to the Navy's waterfront infrastructure.

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1. INTRODUCTION

This NFESC report is a part of the Engineered Wood Project, Phase One, headed by Washington State University and sponsored by the Office of Naval Research. The overall project objective is to develop high performance wood-based products and to integrate these products with existing Navy waterfront maintenance and construction systems. Phase One major objectives are:

1. *Materials Development*: Develop cost effective processing techniques to diversify existing wood/thermoplastic composites and integrate carbon-fiber reinforcement.
2. *Structural Design and Analysis*: Optimize the structural systems to guide design of the structural components.
3. *Recycling*: Investigate methods to clean and reuse creosote-treated piles.
4. *Demonstration Projects*: Demonstrate applications of commercial wood/thermoplastic composites as a replacement for current shore facility components.

2. SCOPE

The descriptions of waterfront components and corresponding Navy requirements reported herein are a subtask of the Phase One demonstration projects. The full task is described in Demonstration Projects, Phase One, Task A of the Project Proposal. Other components of this task which will be reported separately, include potential demonstration site descriptions and requirements, need and risk assessments of potential sites, prioritization, and selection of demonstration sites,

In this report NFESC has identified and fully described areas where wood-based materials can be used to strengthen or replace existing waterfront structures. Coupled with these descriptions are requirements for these components, including materials specifications and critical properties as applicable, gleaned from Navy criteria documents. These component descriptions and requirements along with a consideration of commercially available wood-plastic composites design characteristics will be used to develop a list of product opportunities of highest potential value to the Navy's waterfront infrastructure.

3. COMMERCIALLY AVAILABLE WOOD-PLASTIC COMPOSITES

Three commercially available wood-plastic composites will be considered as replacement materials for selected demonstration projects. These are: Trex, Strandex, and Timbertech. Appendix A provides a description of product characteristics. It is anticipated that the phase I demonstration projects will employ one or more of the selected, commercially available wood-plastic composites as direct replacements for waterfront wood components.

In effect, the Phase I demonstration projects will test the efficacy of engineered wood pieces that replace sawn boards, dimension lumber, timbers, as either decking, pile caps, etc. The engineered wood, however, is much more flexible than sawn wood in terms of available shapes that can be used and need not exactly match the replaced wood component shapes. That is, function rather than form will be the primary consideration.

4. CANDIDATE WATERFRONT COMPONENTS

There are no universal waterfront structural designs. Although Navy design criteria must be considered, each pier, wharf, quaywall or other waterfront structure is designed and constructed in accordance with specific site requirements and local custom. Various waterfront wood components, however, are commonly employed and are described below.

Since the commercially available wood-plastic base materials may not exhibit sufficient bending strength or creep resistance for some waterfront wood component applications, only those components that do not necessarily require these properties will be considered as candidates for phase I demonstration projects.

4.1. WOOD PIER COMPONENTS

- Decking. Working surface of a wharf, pier or vessel (Figures 1, 2, 3, 4)
- Bracing. (Figures 1, 3)
- Batter piles (Figure 1)
- Bearing piles (Figures 1, 2, 3)
- Pile caps (Figures 1, 2, 3)
- Stringers (Figures 1, 2, 3, 4)
- String pieces (curbs) (Figures 1, 2)
- Spacer blocks (Figures 1, 2)
- Steps/ladders
- Hand rails (Figures 3, 4)

4.2. WOOD FENDER COMPONENTS

- Chocks (Figure 1, 5)
- Wales (walers) (Figure 1, 5)
- Fender piles (Figure 1, 5)
- Camel logs (Figure 1, 6)

4.3. DOLPHINS

- Piles (Figures 7, 8)

4.4. DEEP-DRAFT CAMEL/SEPARATOR

- Chocks (Figures 9,10, 11)
- Walers (Figures 9,10, 11)
- Fender piles (Figures 9,10, 11)

4.5. FRAMED TIMBER CAMEL

- 12-inch by 12-inch wood timber (Figures 5, 12)

4.6. BULKHEADS

- Piles (Figure 13)
- Walers (Figure 13)
- Walls (Figure 13)

4.7. DRYDOCK COMPONENTS

- Keel blocks (Figure 14)
- Caisson seals (Figure 14)

4.8. MARINE RAILWAY COMPONENTS

- Railroad ties
- Cradle

4.9. BACKING PANELS

- Wall (Figure 15)

4.10. SMALL BRIDGES

- Auto or pedestrian (Figure 16)

4.11. WALKWAYS

- Walkways or catwalks (Figure 7)

These are permanent personnel accesses installed between shore and various elements of piers and wharves, e.g. between a pier and a mooring dolphin.

4.12. SMALL BARGES OR FLOATS

- Floats/Working Platforms (Figure 17)

4.13. BROWS

Brows are used for access to landing floats from the pier or wharf, or to access a berthed ship from the deck (Figures 18, 19).

5. DESIGN REQUIREMENTS FOR WOOD-BASED MATERIALS

Except for round poles or piles, there are no special Navy design requirements or specifications for wood pieces used for Navy waterfront construction. Instead, design requirements and specification of wood pieces for waterfront construction follow National Design Specifications (NDS) for Wood Construction. Tables 2 through 5 of the NDS Supplement provide design values for the various commercially available timber species and commodities. Therefore, engineered wood pieces that meet these NDS design values can be used as direct replacements for the original wood pieces.

Different waterfront wood components are subjected to different physical and mechanical demands. Tables 5-1 and 5-2 provide a list of critical properties for selected

components. It is recommended that wood-based materials meet or exceed the defined critical properties of the end-use item.

TABLE 5-1. CRITICAL PHYSICAL PROPERTIES

| Functional Member | Density | Dimensional Stability | Working Qualities | Weathering Resistance | Chemical Resistance | Coefficient of Friction |
|-------------------|---------|-----------------------|-------------------|-----------------------|---------------------|-------------------------|
| Bearing Pile | | X | | | | |
| Fender Pile | | | | | | X |
| Cross Bracing | | X | X | X | | |
| Pile Cap | | X | X | X | | |
| Chock/Wale | | X | X | X | | |
| Stringer | | X | X | X | | |
| Decking | | X | X | X | X | X |
| Camel | X | | | | | X |

TABLE 5-2. CRITICAL MECHANICAL PROPERTIES

| Functional Member | Modulus of Elasticity | Modulus of Rupture | Work to Max Load | Shear Strength | Compr. Strength | Tensile Strength | Impact Bending | Creep Resist | Hardness |
|-------------------|-----------------------|--------------------|------------------|----------------|-----------------|------------------|----------------|--------------|----------|
| Bearing Pile | X | X | X | X | X | X | | X | |
| Fender Pile | X | X | X | X | X | X | X | | X |
| Cross Bracing | X | X | X | X | X | X | | X | |
| Pile Cap | | | | | X | | | X | |
| Chock/Wale | | | | | X | | | | |
| Stringer | X | X | X | X | X | X | | X | |
| Decking | X | X | X | X | X | | X | X | X |
| Camel | X | X | X | X | X | | X | | X |

Wood waterfront construction materials are specified in terms of lumber size and quality. Typically, the wood is then cut on site to meet construction or component needs. Commercial sawn lumber and logs used in waterfront construction can be categorized as follows (Table 5-3):

- **Boards** – lumber that is nominally less than 2 inches thick and 2 or more inches wide

- **Dimension lumber** – lumber with a nominal thickness of from 2 to 4 inches thick and a nominal width of 2 or more inches
- **Beams and Stringers** – lumber that is nominally 5 inches or more thick, with width more than 2 inches greater than thickness.
- **Posts and Timbers** – lumber that is nominally 5 inches or more in least dimension with width not more than 2 inches greater than thickness.
- **Decking** – lumber that is 2 to four inches nominal thickness, grooved and intended for use as a roof, floor, or wall membrane.
- **Round piles or poles** – cut logs typically 12 to 18 inches in diameter.

TABLE 5-3. LUMBER TYPE FOR VARIOUS APPLICATIONS

| APPLICATION | COMPONENTS | LUMBER |
|--|--|--|
| Piers | Decking Bracing Batter piles Bearing piles Pile caps Stringers String pieces (curbs) Spacer blocks Steps/ladders Hand rails | Decking or Boards Timbers, Dimension lumber Large timbers, round or square Large timbers, round or square Timbers Stringers Timbers Dimension lumber Boards, specialty items Boards, Dimension lumber |
| Fendering | Chocks Wales (walers) Fender piles Camel logs | Timbers Timbers Large timbers or cut logs Very large timbers, cut logs |
| Deep draft camel Framed timber Camel | Chocks Walers Fenders | Timber Timber Timber |
| Bulkheads | Piles Walers Walls | Large timbers, round or square Dimension lumber, Timbers Dimension lumber, Timbers |
| Drydocks | Keel blocks Caisson seals | Timbers attached to concrete Prefabricated or specialty items |
| Marine railways | Railroad ties | Timbers |
| Small bridges | | |
| Walkways | | |
| Small barges, floats | | |

6. DESIGN REQUIREMENTS FOR WOOD-BASED COMPONENTS

6.1. BACKGROUND

Virtually all wood used in waterfront construction must be pressure-treated with a preservative. This requirement is not expected to apply to wood-plastic composites because the plastic component should protect the wood component from damage by fungi or wood borers. However, because NDS design values apply equally to preservative-treated wood, the design requirements for the wood-plastic materials will be extracted from the average design values of untreated southern pine and Douglas-fir. An exception is that load duration factors greater than 1.6 should not apply to structural members pressure-treated with water-borne preservatives or fire retardant chemicals. In addition, the Navy requires an adjustment of design values for wood load-bearing piles as indicated in Table 5-4 (Table 4 of MIL-HDBK-1025/6).

While there are no special Navy design requirements for sawn wood pieces, various recommendations and requirements are provided for specific applications and for the use of new materials, techniques and methods.

6.2. GENERAL REQUIREMENTS

6.2.1. From MIL-HDBK-1001/2 Materials and Building Components (July 87):

- 2.5.1. Permanent Construction: .. "Select finishes, materials and systems for low maintenance and life cycle costs based on 25 years."
- 2.8. New Materials: The use of new materials is encouraged, but specific policies and procedures must be followed to ensure that the standards and qualities of the Department of the Navy are maintained and enhanced.
 - 2.8.1. Navy Policy: ... "new materials, equipment and methods must be adequately tested and proven by actual performance before adoption. Newly developed materials, equipment and methods not included in NAVFAC guide specifications may be used in limited applications with prior approval by the NAVFACENGCOM Engineering Field Division..."
 - 2.8.2. NAVFAC Procedures: New materials, equipment or methods proposed to NAVFAC must meet the following prerequisites:
 - a) The item must equal or exceed minimum standards for quality and performance currently included in other criteria
 - b) The in-place cost of the item must compete with other acceptable products, or the premium cost of the item must result in long term savings in maintenance or operation costs

TABLE 5-4. PROPERTIES OF TREATED WOOD

| TYPE OF TREATMENT | AVERAGE PROPERTIES | | | | | | | |
|-------------------|--------------------|-----|-------------------------------|-----|-----------------------------------|-----|----------------------------|-----|
| | MODULUS OF RUPTURE | | MODULUS ELASTICITY IN FLEXURE | | AVERAGE ABSORB. ENERGY IN FLEXURE | | COMPRESSIVE STRENGTH E_c | |
| | psi | % | 10^6 psi | % | in-lb/in. ³ | % | psi | % |
| Fir | | | | | | | | |
| Untreated | 8,394 | 100 | 1,922 | 100 | 6,388 | 100 | 3,346 | 100 |
| Cresosote | 6,862 | 82 | 1,664 | 82 | 4,202 | 66 | — | — |
| ACA dual | 6,111 | 73 | 1,637 | 80 | 3,059 | 48 | 2,714 | 81 |
| CCA dual | 3,844 | 46 | 1,171 | 61 | 3,364 | 53 | 2,333 | 70 |
| ACA | 6,620 | 67 | 1,416 | 74 | 2,078 | 33 | 2,462 | 74 |
| Pine | | | | | | | | |
| Untreated | 8,007 | 100 | 1,942 | 100 | 6,240 | 100 | — | — |
| Cresosote | 6,950 | 74 | — | — | — | — | — | — |
| ACA dual | 4,725 | 59 | 1,668 | 81 | 2,829 | 64 | — | — |
| CCA dual | 4,167 | 52 | 1,441 | 74 | 2,413 | 46 | — | — |
| ACA | 6,534 | 69 | 1,538 | 79 | — | — | — | — |
| GCA | 5,410 | 68 | — | — | — | — | — | — |

NOTES: 1) Where no value is provided, it is because of the large spread in measured values for a small number of samples.

2) % = the percent of the value for untreated wood.

3) Source: Civil Engineering Laboratory, Technical Note (TN) No. NT536-Mechanical Properties of Preservative Treated Marine Piles — Results of Limited Full-Scale Testing.

- c) The item must be readily available in quantity and in wide geographical areas
- d) The merits of the item must have approved laboratory certification or evidence of satisfactory use under conditions similar to the proposed application
- e) Quality control of manufacturing processes and installation techniques must be guaranteed

- f) Proposed item must be nonrestrictive enough to admit other available and equally acceptable competition
- 3.2. Construction systems
- 3.2.1.1. a) Wood frame: "Wood frame systems are not generally recommended for major or permanent construction projects, although laminated or other structural wood systems can be used for certain building types ..."
- 3.2.3.1. a) Wood walls: "Exterior walls of wood are not permitted for most major or permanent building types ... [they] require constant maintenance, deteriorate rapidly, and offer little fire protection or additional insulation value."
- 4.4. Wood and Plastics
- 4.4.1. Wood: use NFGS-06100 Rough Carpentry and NFGS-06200 Finish Carpentry.
- 4.4.3. Plastic Laminate: " .. [can be used] for architectural woodwork items .."

6.2.2. From MIL-HDBK-1002/1 Structural Engineering, General Requirements (November 87)

Alternative materials shall provide:

- consistent factor of safety
- fire safety per MIL-HDBK-1008/1

Structures classification:

Class A: bridges, trestles, viaducts and their components

Class B: building-type structures, including portions of piers and wharves

Class C: structures supporting heavy lift cranes, airport runways, storage tanks, ..

6.2.3. From MIL-HDBK-1002/2A Loads (October 96):

Supersedes MIL-HDBK-1002/2 Structural Engineering, Loads (Sep 88).

Loads in this MIL-HDBK are for general Class A and B structures. Loads for Class C structures are application specific; e.g., use MIL-HDBK 1025/1 for Piers and Wharfs.

6.2.4. From MIL-HDBK-1002/5 Timber Structures (March 87):

Design standards for Structures:

- | | |
|--------------|--|
| Class A | AASHTO - Standard Specifications for Highway Bridges - for bridges |
| | AREA - Manual for Railway Engineering - for railway bridges |
| Class B, C | NFPA - National Design Specification for Wood Construction |
| | AITC - Timber Construction Manual |
| Plywood | APA - Plywood Design Specs. |
| Wood Trusses | TPI - Purdue University AES Research Bulletin No. 714 and 727. |

| | |
|-------------------------|---|
| Details of design: | |
| Stress grade lumber | NFPA standard |
| Nonstress grade lumber | use "standard" grade of better for <u>blocking</u> , bridging, etc.. |
| Plywood | APA standard, species group 1, 2, or 3 |
| Nondomestic wood | Tropical woods: use strength from supplier (check with tests) and 25% to 33% of strength for allowables |
| Plywood | Some specs on allowables are included |
| Preservative treatments | AWPA - Book of Standards (not applicable to wood-plastic composites) |

6.2.5. From MIL-HDBK-1002/6 Aluminum Structures, Composite Structures, Structural Plastics, Fiber-Reinforced Composites (June 1987):

Section 4: Structural Plastics and Fiber-Reinforced Composites

- 4.2.1. General: "There is no general design specification for design of thermoplastic or fiberglass reinforced plastic (FRP) components." Some guidance in ASCE Structural Plastics Design Manual and Structural Plastics Selection Manual.
- 4.2.2. FRP tanks, Ducts, Equipment.
- 4.2.3. FRP Pultruded Shapes
- 4.2.4. FRP Panels.
- 4.2.5. Tension Membranes
- 4.2.6. Thermoplastics
- 4.2.7. GFRC Wall Panels
- 4.2.8. FRC (Fiber Reinforced Concrete)
- 4.2.9. Polypropylene Fiber Reinforced Slabs on Grade

Appendix B:

1. "Apparent stiffness and strength reduce with long duration loads."
2. "Severe environment .. may degrade structural properties.."
3. "Low stiffness and directional properties require special consideration of buckling and deflection .."
4. "Lack of ductility .. requires accurate stress analysis and design to eliminate stress concentrations .."
5. "Low fracture toughness .. requires careful detailing to avoid notches and stress raisers.."
6. "High coefficient of thermal expansion requires careful design to accommodate larger movements or to account for structural consequences of movement restraint."
7. "Few thermoplastics .. can be used .. above 200 F."
8. "Low fire resistance and combustion products that include toxic fumes exclude many plastics .."
9. ".. long term exposure to moisture and weathering usually produces a significant reduction in the strength properties, ductility and toughness."
10. "Movements due to thermal and moisture change and restraint of such movement may induce significant stresses .."

6.3. WOOD PIER COMPONENT STRUCTURAL REQUIREMENTS

6.3.1. From MIL-HDBK-1025/1 Piers and Wharfs (March 87, last update June 94)

The complete military handbook is relevant to this section. A partial table of contents is provided below to highlight the most relevant topics.

Section 3: Loads

- 3.1. Dead Loads
- 3.2. Vertical Live Loads
- 3.3. Horizontal Loads
- 3.4. Load Combinations

Section 4: Structural Design

- 4.1. Types of Construction
- 4.2. Construction Materials
- 4.3. Allowable Stresses
- 4.4. Deck Structure Design
- 4.5. Substructure Design
- 4.6. Floating Structures
- 4.7. Mooring Hardware
- 4.8. Mooring Dolphins
- 4.9. Miscellaneous Considerations

Section 5: Fender Systems

- 5.1. General
- 5.2. Berthing Energy Determination
- 5.3. Types of Fender Systems
- 5.4. Selection and Design of Fender Systems

Section 6: Separators

- 6.1. Function and Application
- 6.2. Separator Types
- 6.3. Loads
- 6.4. Geometry
- 6.5. Stability
- 6.6. Miscellaneous

Section 7: Access Facilities

- 7.1. General
- 7.2. Landing Float
- 7.3. Brow or Gangway

- 7.4. Brow Platforms
- 7.5. Walkway or Catwalk
- 7.6. Ramps
- 7.7. Utility Booms
- 7.8. Fuel Loading Arm
- 7.9. Access Ladders

6.3.2. From MIL-HDBK-1025/6 General Criteria for Waterfront Construction (May 88)

Section 2: Piling

2.1.1.1. Capacity as a structural member: "... treat piles as columns having an unbraced length as shown in Figure 1." Alternatively, and for wood piles, assume point of fixity to be about 10 ft below the mud line for soft, cohesive soils, 8 ft for granular and medium cohesive soil, and 5 ft otherwise. The effective length factor K is assumed to be between 0.5 and 0.75. Note: these provisions do not apply if embedment is less than 10 ft into firm material, or 20 ft into soft or loose material.

- 2.2.1. Untreated timber piles
- 2.2.2. Treated timber piles
- 2.2.3. Untreated and treated timber piles

6.3.3. NFGS-02458B Timber Piles (June 96) and NFGS-02461A Wood Marine Piles (March 96)

These are guide specifications for timber piles. The full text is provided in Appendices B and C.

6.4. WOOD DECK REQUIREMENTS

6.4.1. From MIL-HDBK-1025/1 Piers and Wharfs (March 87, last update June 94)

Requirements for wood decks are included in Section 4: Structural Design

6.4.2. From MIL-HDBK-1025/6 General Criteria for Waterfront Construction (May 88)

Relevant sections include:

- 3.2. Deck
 - 3.2.1. Timber: "Do not use creosote treatment on walking surfaces or surfaces which normally will be touched by people (handrails, for example)."

6.5. WOOD PIER SUBSTRUCTURE REQUIREMENTS (Pile Caps, Stringers, and String Pieces)

6.5.1. From MIL-HDBK-1025/1 Piers and Wharfs (March 87, last update June 94)

Requirements for wood pier substructures are included in Section 4: Structural Design

6.5.2. From MIL-HDBK-1025/6 General Criteria for Waterfront Construction (May 88)

Requirements for wood pier substructures are included in Section 3: Deck and Substructure Framing and Bracing

3.1. Pile caps

3.1.2. Timber (typically preservative-treated Southern Pine and Douglas Fir)

Table 4: Properties of untreated and treated Fir and Pine (shown in this document as Table 5-2).

6.1. Evaluation of strength of existing materials

6.1.2. Number of tests required to establish strength of ungraded materials: "The strength of material to be assumed for strength evaluation of the structure shall be the value for which sampling and test indicates to have a 95% probability of being exceeded. Not less than 4 samples shall be tested." The material strength is given as $S = \bar{x} - t\sigma/2$, where \bar{x} is the average, σ is the standard deviation, and t varies from 2 to 5 when the samples tested vary from 4 to 25.

6.5.3. NFGS-02398 Pier Timberwork (Dec 95)

This guide specification provides guide specifications for timber pier components. The full text is provided in Appendix D.

6.6. WOOD FENDER SYSTEMS REQUIREMENTS

For piling requirements see Section C.

6.6.1. From MIL-HDBK-1025/1 Piers and Wharfs (Mar 87, last update Jun 94):

Requirements for wood pier substructures are included in Section 5. Fendering
5.1 General

- 5.2 Berthing Energy Determination
- 5.3 Types of Fender Systems
- 5.4 Selection and Design of Fender Systems

6.7. WOOD COMPONENT REQUIREMENTS OF PRINCIPALLY NON-WOOD FENDER SYSTEMS

Backing panel

6.8. WOOD COMPONENT REQUIREMENTS OF DEEP-DRAFT CAMEL/SEPARATOR AND FRAMED TIMBER CAMEL

6.8.1. From MIL-HDBK-1025/1 Piers and Wharfs (Mar 87, last update Jun 94):

Requirements for wood camels/separators are included in Section 6: Separators

- 6.1. Function and Application
- 6.2. Separator Types
- 6.3. Loads
- 6.4. Geometry
- 6.5. Stability
- 6.6. Miscellaneous

6.9. TIMBER DOLPHIN REQUIREMENTS

For piling requirements see Section C.

6.9.1. From MIL-HDBK-1025/1 Piers and Wharfs (Mar 87, last update Jun 94)

Requirements for wood camels/separators are included in Section 4: Structural Design

- Mooring Hardware
- Mooring Dolphins

6.10. TIMBER BULKHEAD REQUIREMENTS

For piling requirements see Section C.

6.10.1. From MIL-HDBK-1025/4 Seawalls, Bulkheads, and Quaywalls (Sep 88)

2.1. Definitions

- 2.1.1. Seawall: "A seawall is a soil retaining or armoring structure whose purpose is to defend a shoreline against wave attack. It differs from a breakwater in its capacity as a soil retention structure. Seawalls are forms of shore protection and are not intended for use as berthing facilities."
- 2.1.2. Bulkhead: "A bulkhead is a soil retaining wall structure comprised of vertically-spanning sheet piles or other flexural members. Bulkheads derive their stability through mobilization of passive earth pressures between the mud line and embedded tip, and, in most cases, from a lateral restraint system installed between Mean Low Water (MLW) and top of wall. Bulkheads are installed to establish and maintain elevated grades along shorelines in relatively sheltered areas not subjected to appreciable wave attack, and are commonly used as berthing facilities."
- 2.1.3. Quaywall: "A quaywall is a gravity wall structure having the dual function of providing shore protection against light to moderate wave attack and a berthing face for ships. Its function is similar to a bulkhead but should be chosen when overall height requirements or wave environment severity exceeds the practical capabilities of typical bulkhead constructions. Quaywalls differ from bulkheads and wall-type seawalls in that they do not necessarily retain a soil backfill."

2.2. Selection of type of facility

2.2.1. Bulkheads vs. Seawalls

2.2.2. Bulkheads vs. Quaywalls

3. Seawalls

This section shows types of seawalls (gravity, rubble mound stone revetment, interlocking concrete blocks, stepped face concrete, curved face concrete, combination, filled concrete, etc.). None of them seems to use timber, except perhaps for buried bearing piles.

4. Bulkheads

This section shows types of bulkheads (without relieving platform, with relieving platform and pile anchorage, with relieving platform and deadman anchorage, with relieving platform and batter piles, with double anchor level). Timber can be used for piles (examples K, L in Fig. 14, Fig. 18), fendering (Fig. 25), and also for the wall itself (e.g. tongue and groove, close pile wall in Fig. 27, steel soldier beam and wood lagging in Fig. 28). This would be a good waterfront application for engineered wood.

5. Quaywalls

This section shows types of quaywalls (steel sheet pile cells, timber crib, concrete caisson, masonry/concrete blocks, cyclopean concrete, gabion, reinforced earth, soil-cement block). The timber crib quaywall is the only one that shows use of timber.

6.11. REQUIREMENTS FOR DRYDOCK WOOD COMPONENTS

6.11.1. From MIL-HDBK-1029/1 Graving Drydocks (Jan 89):

Graving drydocks can be made completely out of timber (Figure 4) although this is a temporary application, and for smaller ships (no all-wood drydock was found in MIL-HDBK-1029/3, below). Figures 5 and 6 show ship blocking loads on keel and bilge blocks (up to 149 kips/ft).

8.2.3. Keel blocks: "Compression is the primary stress, but provision must be made to resist uplift, overturning, and horizontal movements induced by eccentric loads, earthquakes, or accidental impacts... Standard composite [concrete and wood] keel blocks (see Figure 10) are rated at 225 long tons (228610 kg) based on allowable stresses for wet timber in compression perpendicular to the grain taken at 250 psi (1724 kPa) for soft caps. For the standard 6 foot center-to-center keel block spacing, this rating represents a 37.5 tons per ft (34014 kg/m) ship load." Note: this last conversion does not seem accurate, it should say (123000 kg/m).

8.2.4. Bilge or side blocks: "Bilge or side blocks are timber, built-up, shaped and located according to dimensions indicated in the table of offsets of docking plan of the vessel. These are designed for 250 psi load applied uniformly over the effective bearing area in contact with the hull of the ship. Each block shall be battened adequately for stability, and the resultant load reaction shall fall within the middle one-third of the base dimension of the block on the dock floor." Note: engineered woods with lower elastic moduli may be better suited for blocking since they allow for more local deformations - however, differential deformations between keel (composite) and bilge blocks may have to be addressed.

8.2.5. Types of construction: "Composite blocks shall be built with wood top and bottom layers [6" by 6" white oak timber typ.], and concrete sandwiched in between." (Figure 10).

Figure 14 shows wood bearing block lining used for the caisson gaskets (4.5" by 19" timber lining with center 5" rubber gasket). Note: this design may have been superseded by all-rubber lining. Note: timber fenders are also used on both sides on the ship hull.

6.11.2. From MIL-HDBK-1029/3 Drydocking Facilities Characteristics (Sept 88):

1.1. Scope: "This handbook presents drydocking facilities characteristics in tabular and figure form for graving drydocks, marine railways, and lifts. Plans are also presented indicating the locations of drydocking facilities in naval shipyards or other naval shore installations."

Examples of marine lifts using wood:

- Patuxent River Naval Air Station marine lifts - timber decks, piles, bracing

Examples of drydocks using wood:

- Charleston Naval Shipyard drydocks no. 3, 4 - use timber piles under concrete
- Hunters Point Naval Shipyard, San Francisco, drydocks no. 5, 6, 7 - timber piles
- Mare Island Naval Shipyard, Vallejo, drydocks no. 2, 3, 4 - timber piles
- Norfolk Naval Shipyard, Portsmouth, drydock no. 1, 2, 3 - timber piles
- Pearl Harbor Naval Shipyard drydock no. 1, 4 - timber piles
- Philadelphia Naval Shipyard drydock no. 1, 2 - timber piles
- Puget Sound Naval Shipyard drydock no. 1 - timber piles

In addition most drydocks use wood for fendering, blocking, and until recently for caisson seat lining. Note that in most cases the timber piles are under the drydock floor and walls, and therefore not accessible.

6.12. MARINE RAILWAY WOOD COMPONENT REQUIREMENTS

6.12.1. From MIL-HDBK-1029/3 Drydocking Facilities Characteristics (Sep 88):

Examples of marine railways using wood:

- Annapolis Naval Station - uses wood for cradle, superstructure framing, piles

6.12.2. From MIL-HDBK-1029/2 Marine Railways (Jun 89)

2.2. Principle of operation: "A marine railway, by utilizing the mechanical advantage of the inclined plane and geared hauling machinery, is able to pull the cradle and vessel out of the water with a combination of horizontal and vertical movements."

2.4. Comparison of Marine Railways, Drydocks, and Graving docks: "A marine railway provides a fast, convenient, and economical method of docking and undocking vessels up to about 5000 tons."

8.1. Cradle Materials: "Most cradle designs have steel frames with wood or steel decking; however, timber cradles may be used for designs of small capacity."

Although not specifically mentioned, it is assumed that the keel and bilge blocks (up to 4 feet in height) would/could be made out of timber.

6.12.3. NFGS-05650A Railroad Track and Accessories (March 96)

This provides guide specifications for railroad track components. The full text is provided in Appendix E.

6.13. REQUIREMENTS FOR WOOD COMPONENTS OF SMALL BARGES OR FLOATS (Working Platforms), WALKWAYS, AND BROWS

6.13.1. From MIL-HDBK-1025/1 Piers and Wharfs (Mar 87, last update June 94)

Requirements for wood camels/separators are included in Section 4: Structural Design Floating Structures

6.13.2. From MIL-HDBK-1025/1 Piers and Wharfs (March 87, last update June 94):

Requirements for wood camels/separators are included in Section 7: Access Facilities

- 7.1. General
- 7.2. Landing Float
- 7.3. Brow or Gangway
- 7.4. Brow Platforms
- 7.5. Walkway or Catwalk
- 7.6. Ramps
- 7.7. Utility Booms
- 7.8. Fuel Loading Arm
- 7.9. Access Ladders

7. CONCLUSIONS

This report has identified and described areas where wood-based materials can be used to strengthen or replace existing waterfront components or structures. Coupled with these descriptions are requirements for these components, including materials specifications and critical properties as applicable, gleaned from military criteria documents. Military standards covered include mostly Military Handbooks and NAVFAC Guide Specifications. Pertinent Guide Specifications have been included as appendices.

These waterfront component descriptions and requirements along with a consideration of commercially available wood-plastic composites design characteristics are used to develop a list of product opportunities of highest potential value to the Navy's waterfront infrastructure.

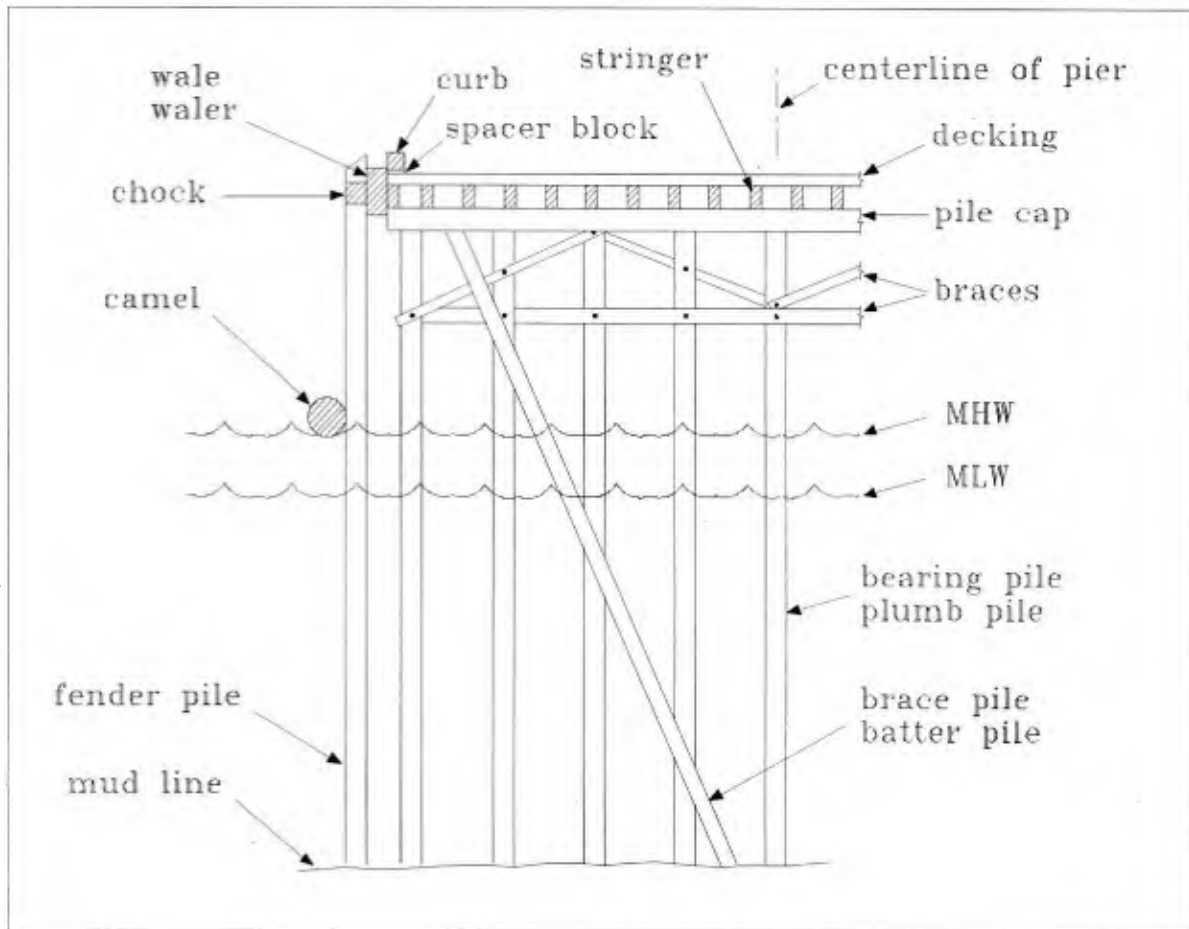


FIGURE 1. TYPICAL PIER CROSS SECTION

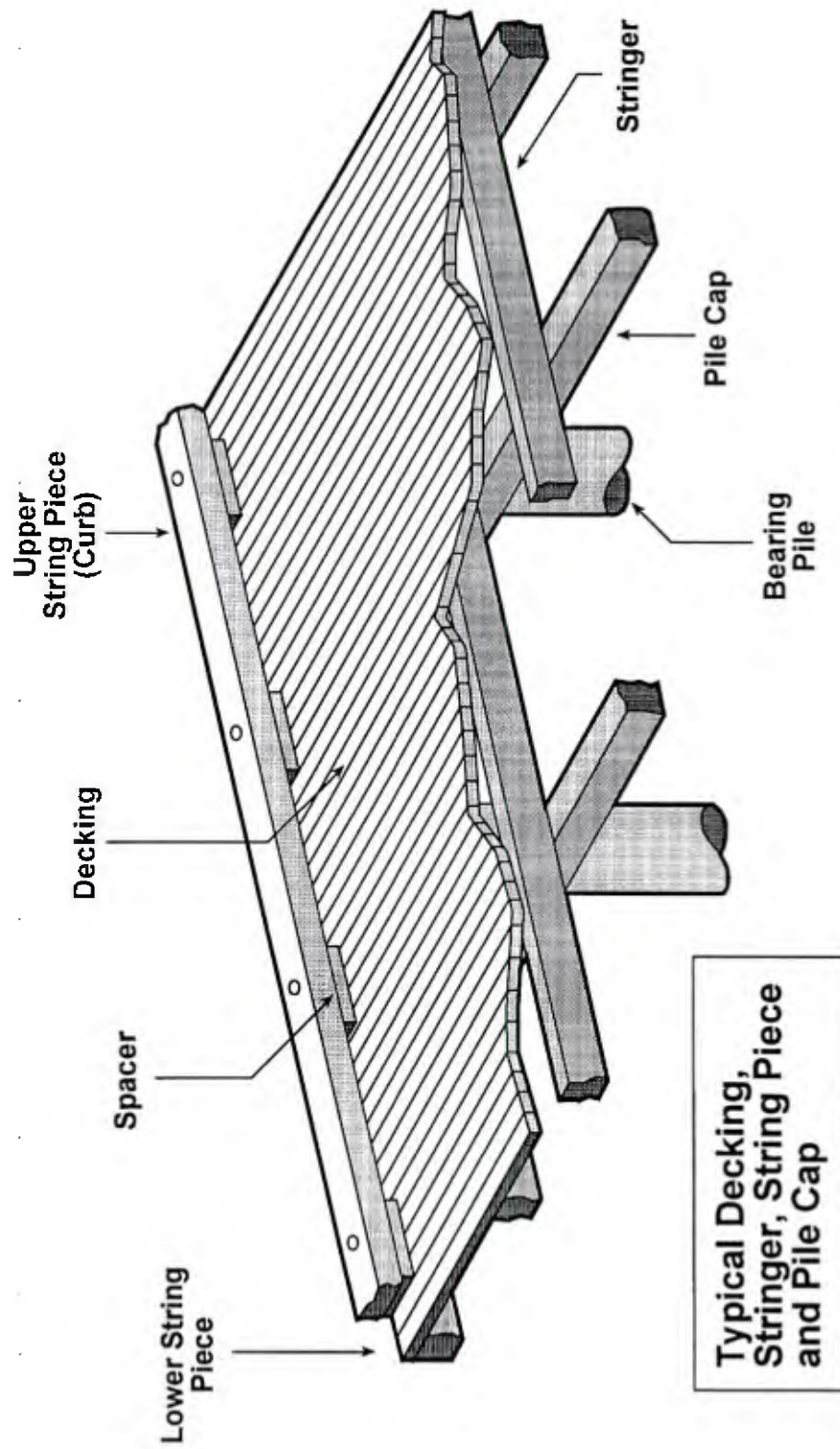


Figure 2. Timber Pile Components

Bracing and Pile Caps

Transverse bracing (X-Bracing) of piles is required in rapidly moving or frequently flooding waters or where depth of water exceeds eight feet. Transverse bracing - when required - is usually 2 x 6 or 2 x 8. G x G square piles (freshwater) or 6 x 6 Marine Grade piles (salt/brackish water) should always consider transverse bracing because of the lack of lateral strength in G x G piles. The combination of pile caps and the stringer system form the part of the structure that carries the decking load (assumed 50 psf) to the piles and into the soil.

Typical Section through Fixed Pier (no scale)

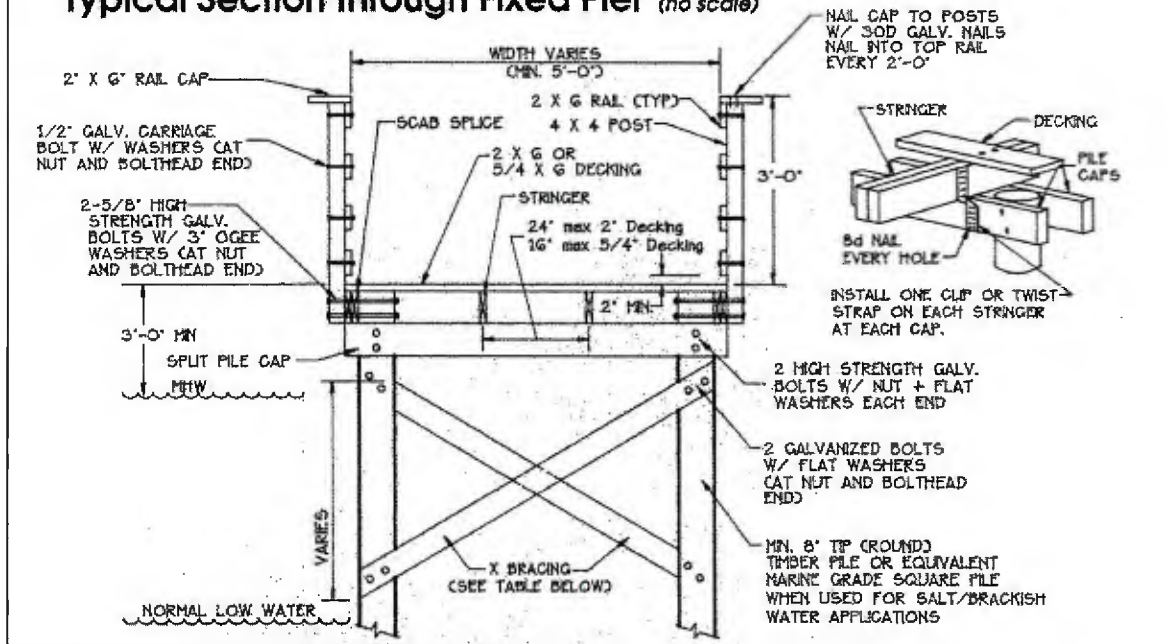


FIGURE 3. TYPICAL SECTION OF A TIMBER PIER

Treated Southern Pine Piers

Decking

The most obvious visual feature of a completed fixed pier is the deck. The higher grades - No. 1 C2' Nominal and Premium (5/4' Nominal) give excellent structural performance with minimal visual imperfections. Nails or decking screws that are carefully aligned and properly installed create a complimentary pleasing pattern.

Typical Fixed Pier Framing Plan (no scale)

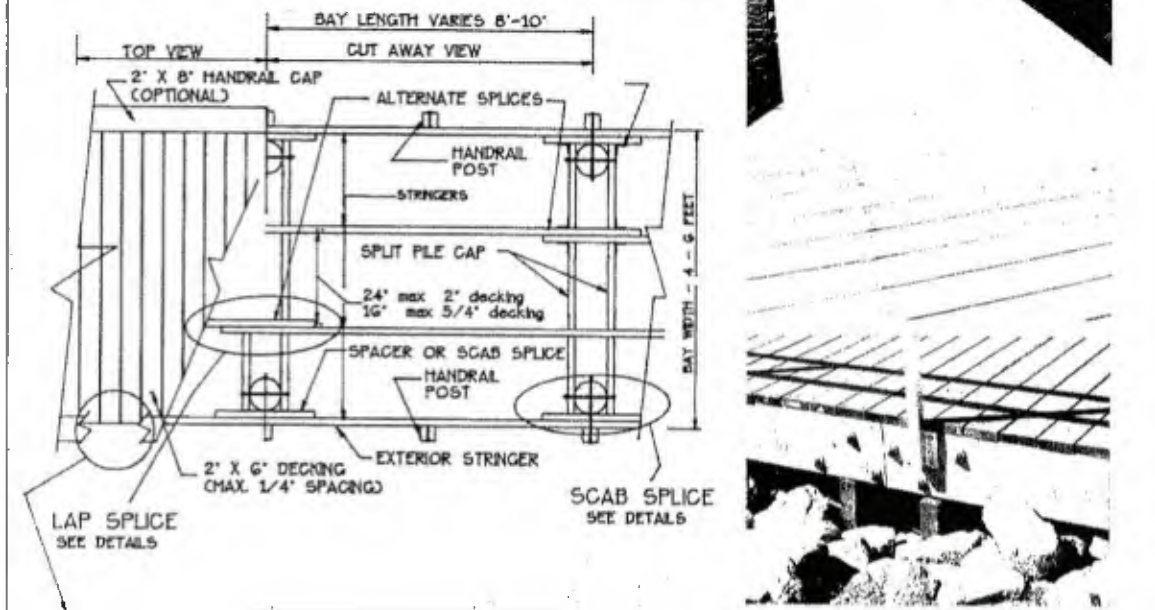


FIGURE 4. TYPICAL TIMBER PIER PLAN



FIGURE 5. PLASTIC FENDER SYSTEM

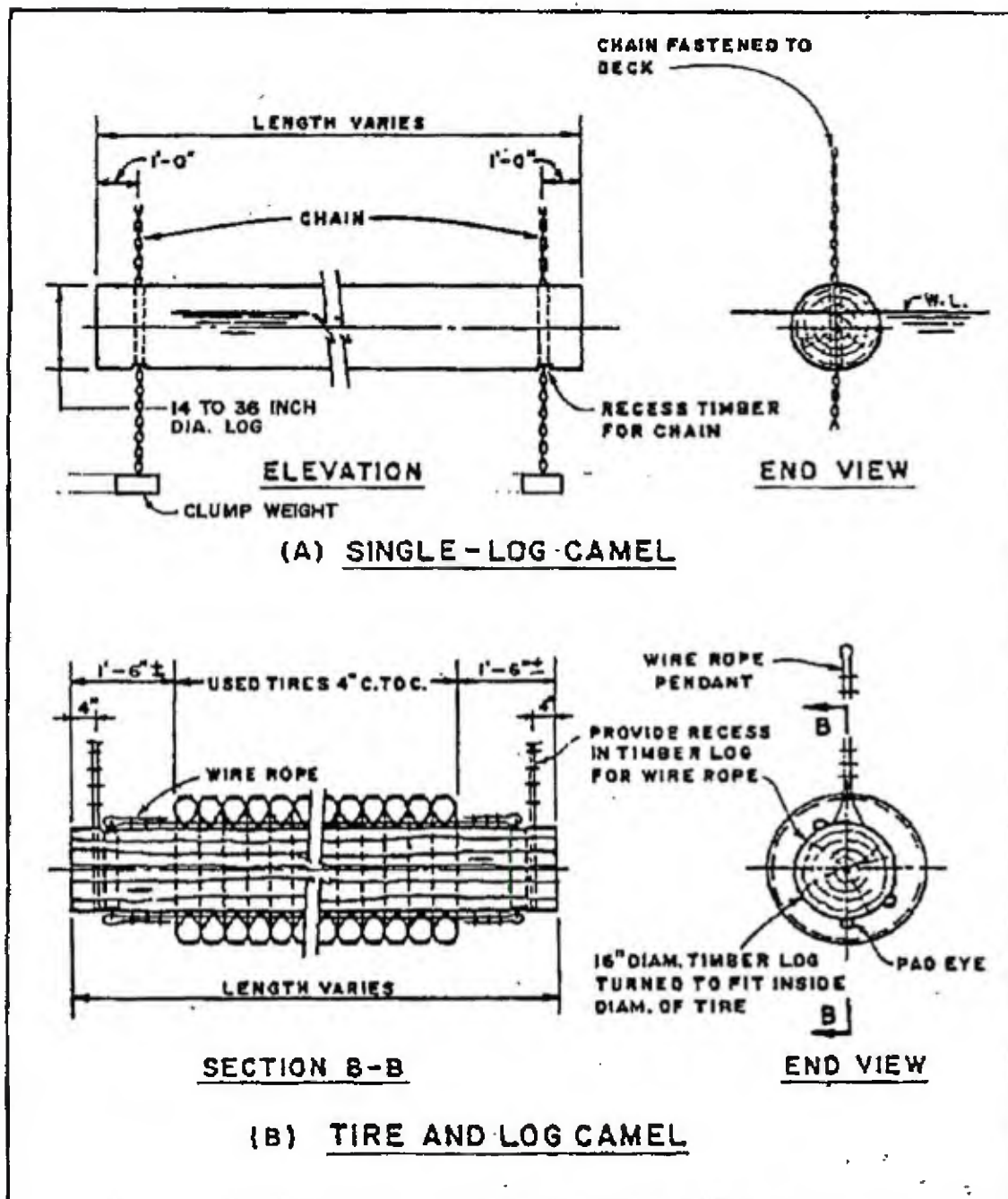


FIGURE 6. LOG CAMELS

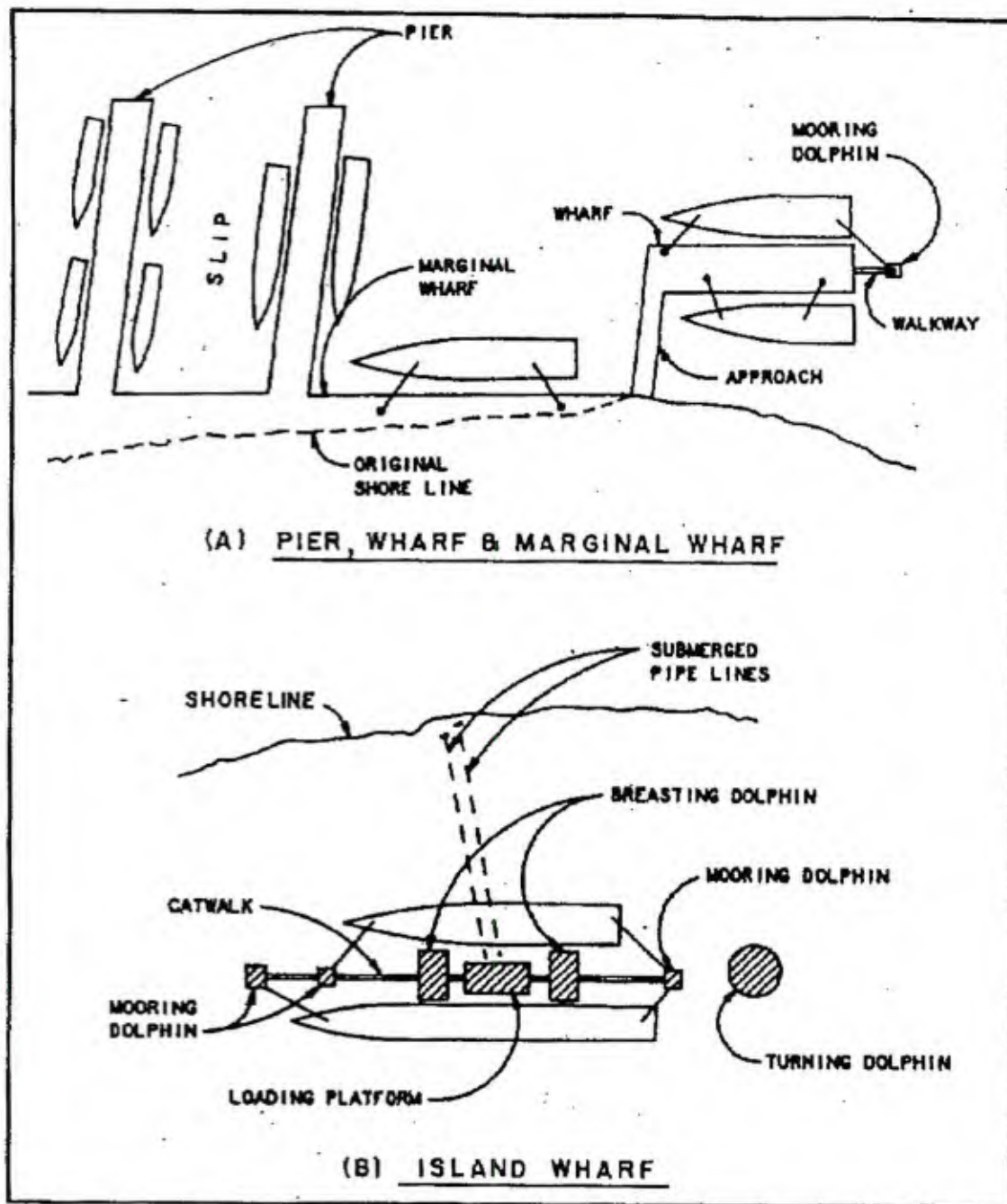


FIGURE 7. PIER AND WHARF TYPES



FIGURE 8. DOLPHIN

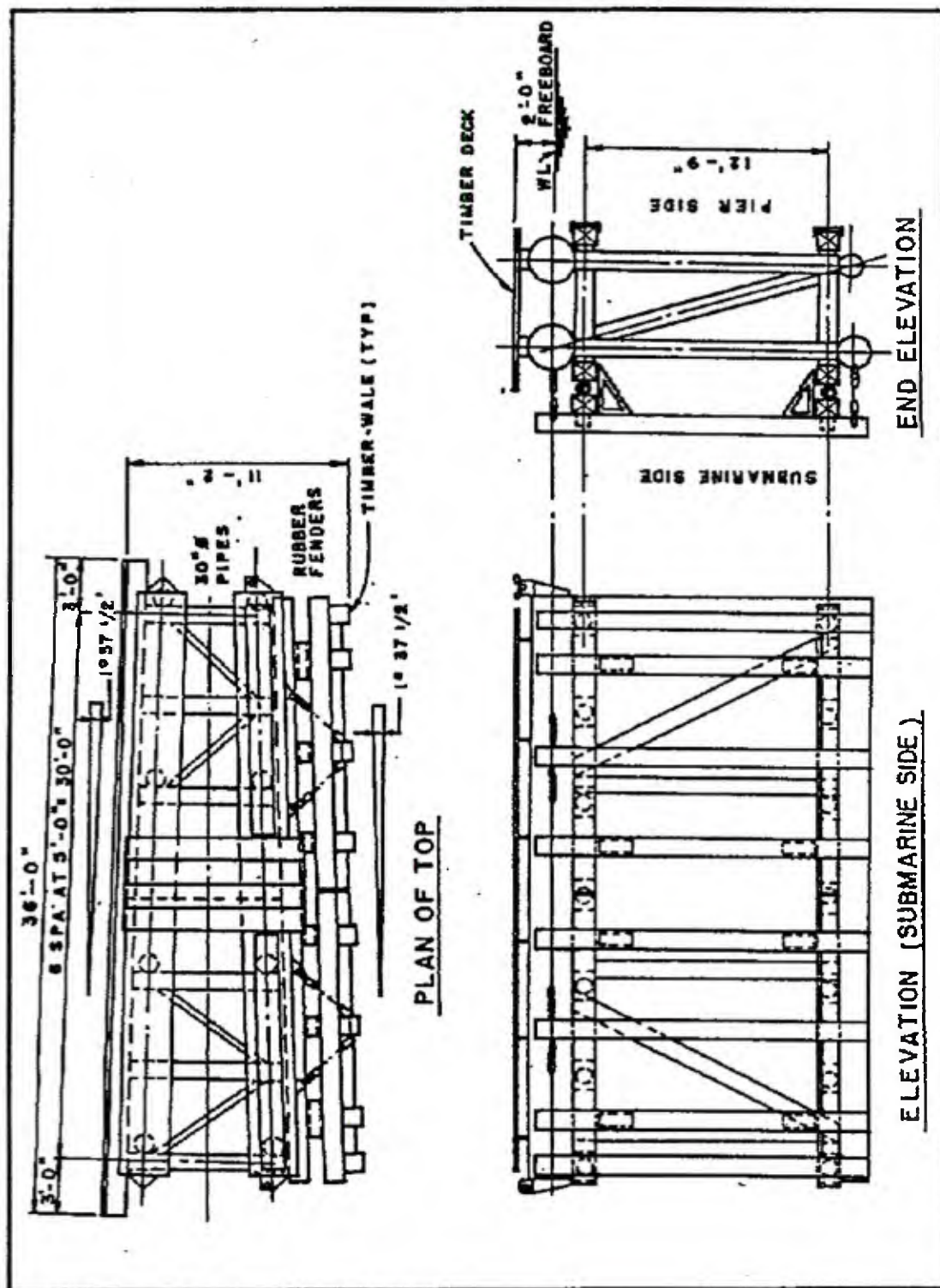


FIGURE 9. DEEP-DRAFT CAMEL FOR SUBMARINES

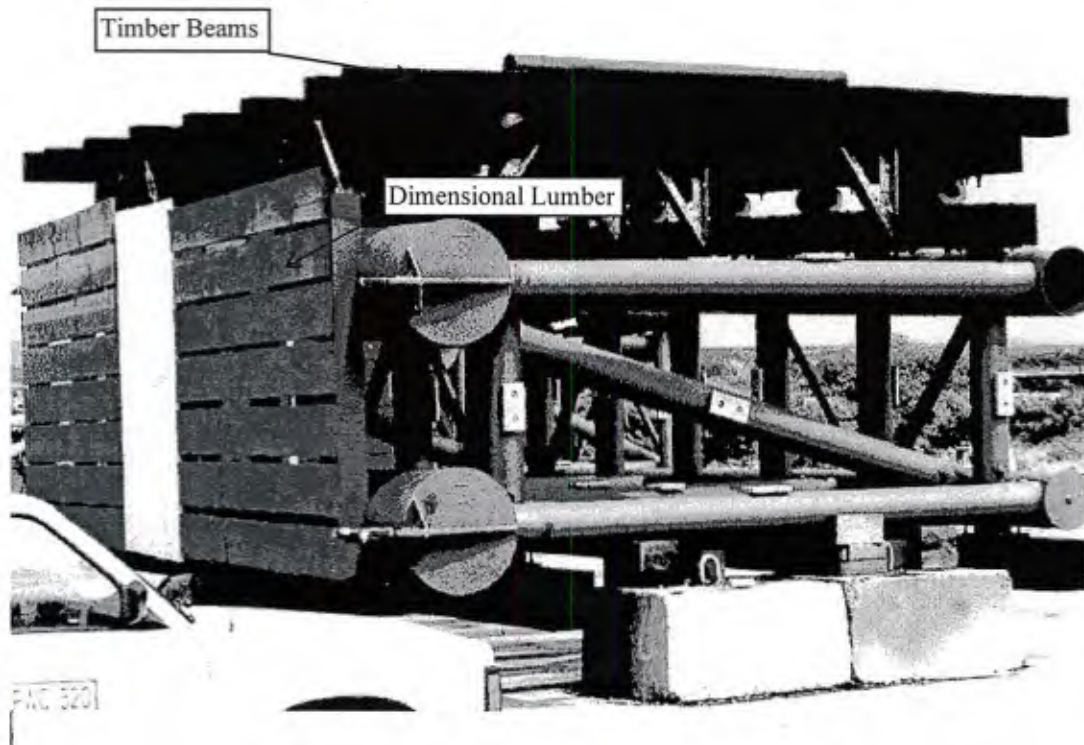


FIGURE 10. DEEP-DRAFT SUBMARINE CAMEL

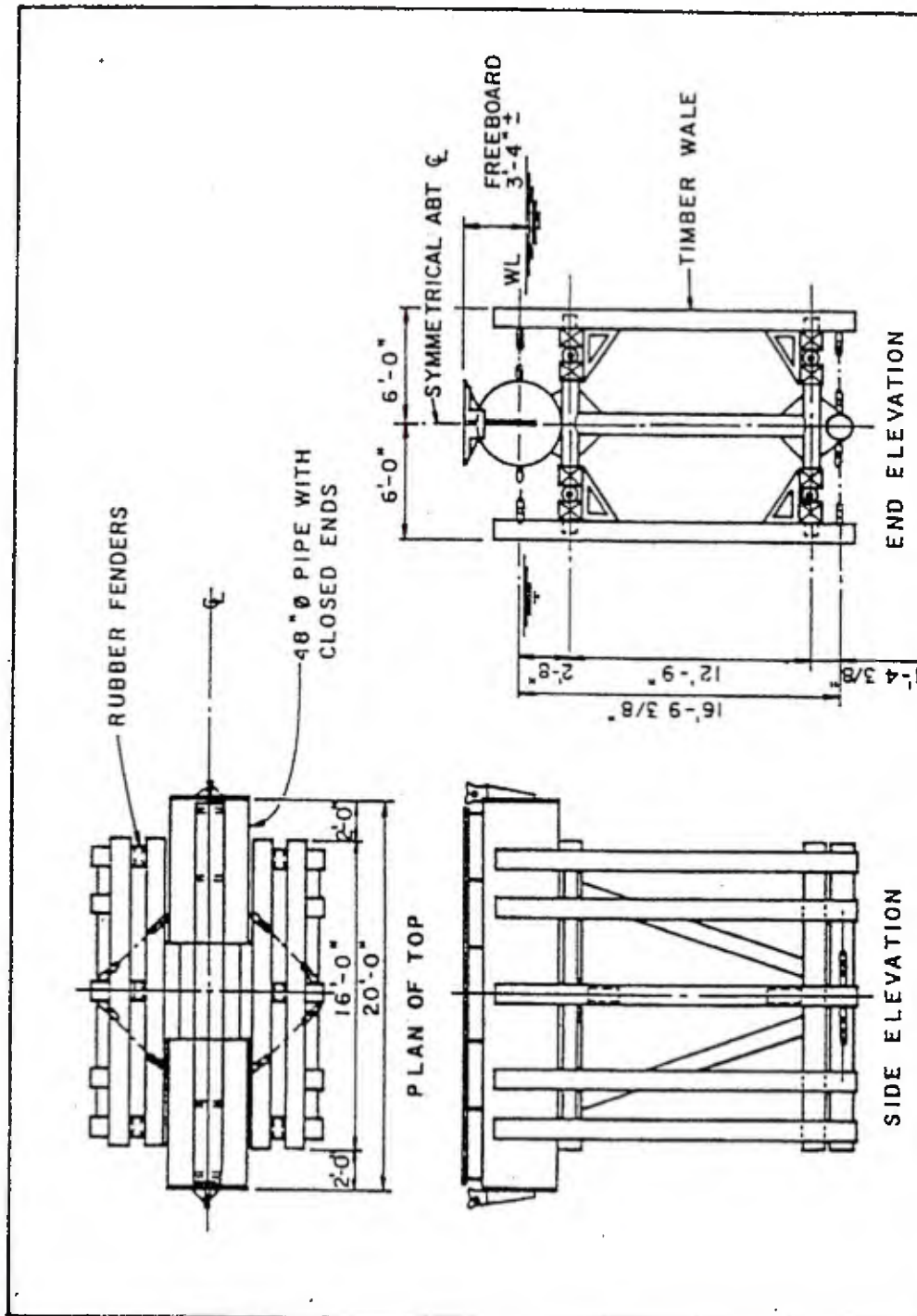


FIGURE 11. DEEP-DRAFT SEPARATOR FOR SUBMARINES

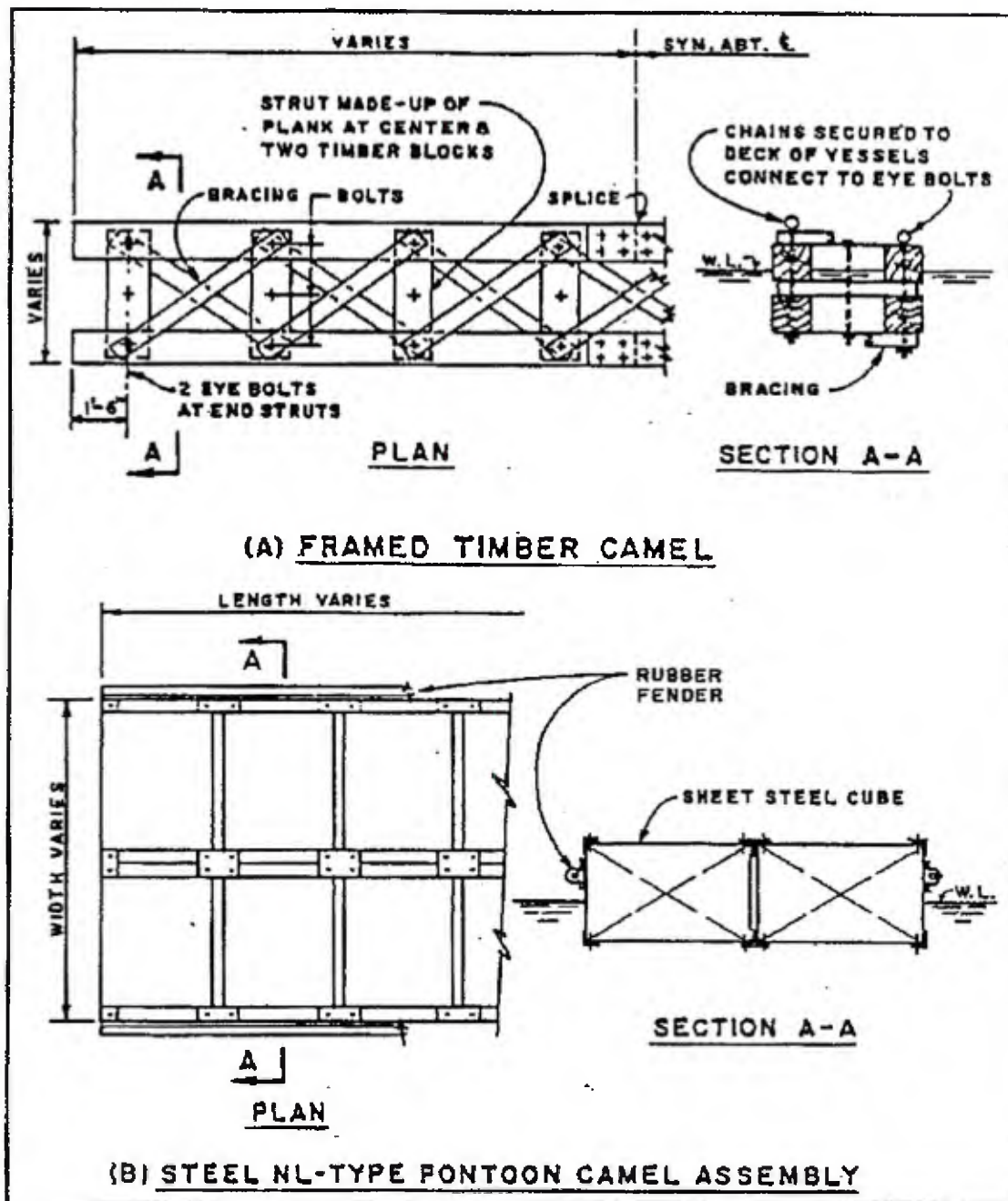
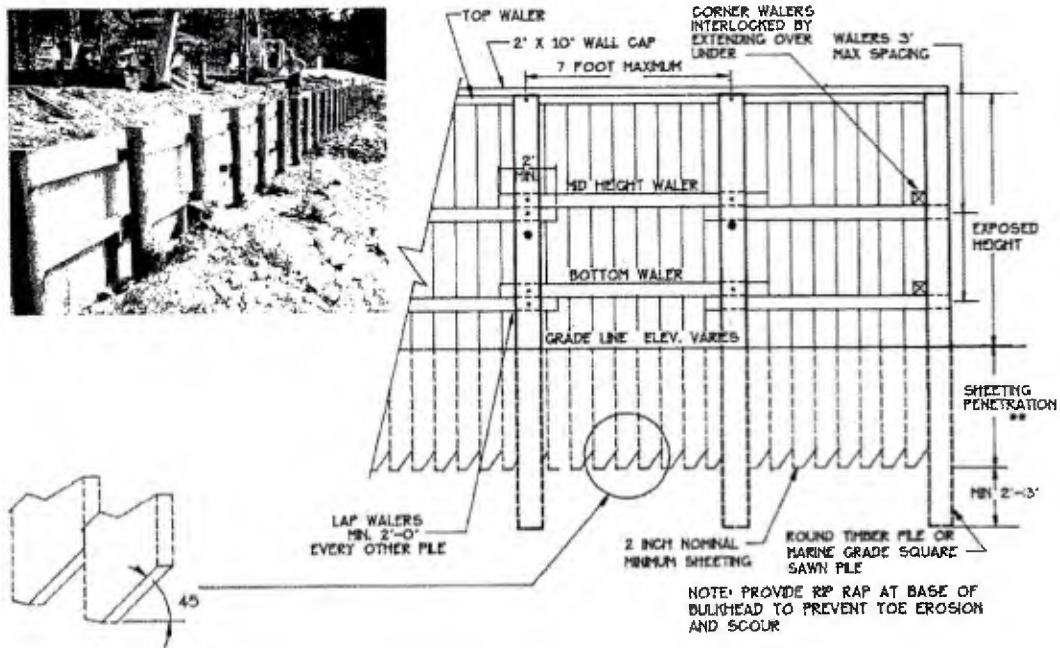


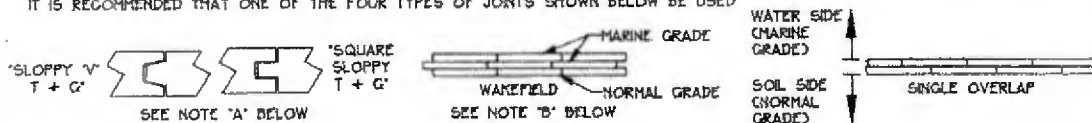
FIGURE 12. TIMBER AND STEEL PONTOON CAMELS

Typical Elevation • Timber Bulkhead (no scale)



Types of Timber Sheet Piles

BULKHEADS SHOULD BE AS TIGHT AND FREE OF CRACKS AS POSSIBLE. IT IS RECOMMENDED THAT ONE OF THE FOUR TYPES OF JOINTS SHOWN BELOW BE USED.



SHEETING NOTE 'A' TONGUE PROFILE SHOULD FIT LOOSELY IN GROOVE AND NEEDS TO BE 3/4" LONG FOR 2" DIMENSION TIMBER AND 1" FOR 3" AND 4" TIMBERS.

SHEETING NOTE 'B' "WAKEFIELD" PATTERN IS FAIRLY NORMAL FOR 1" RESIDENTIAL APPLICATIONS, AND BOTH MARINE GRADE AND NORMAL GRADES MAY BE USED.

FIGURE 13. TIMBER BULKHEAD

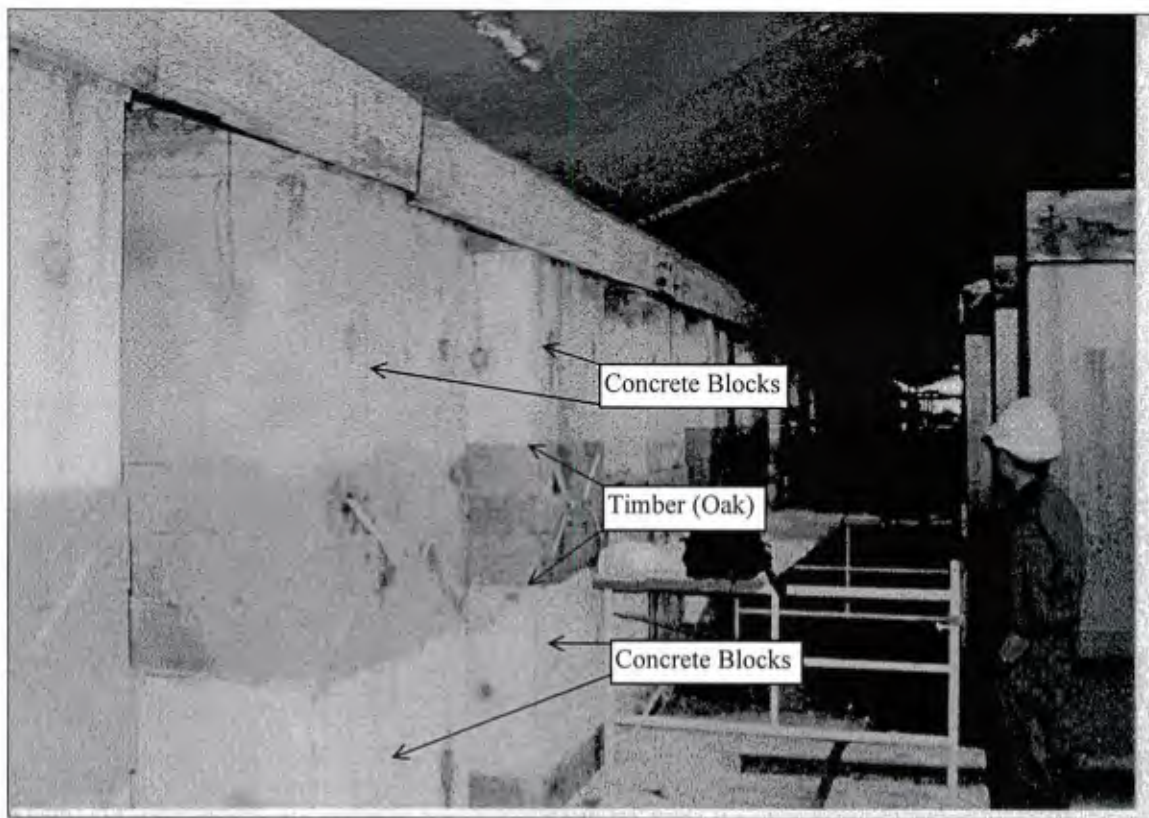


FIGURE 14. KEEL BLOCKS

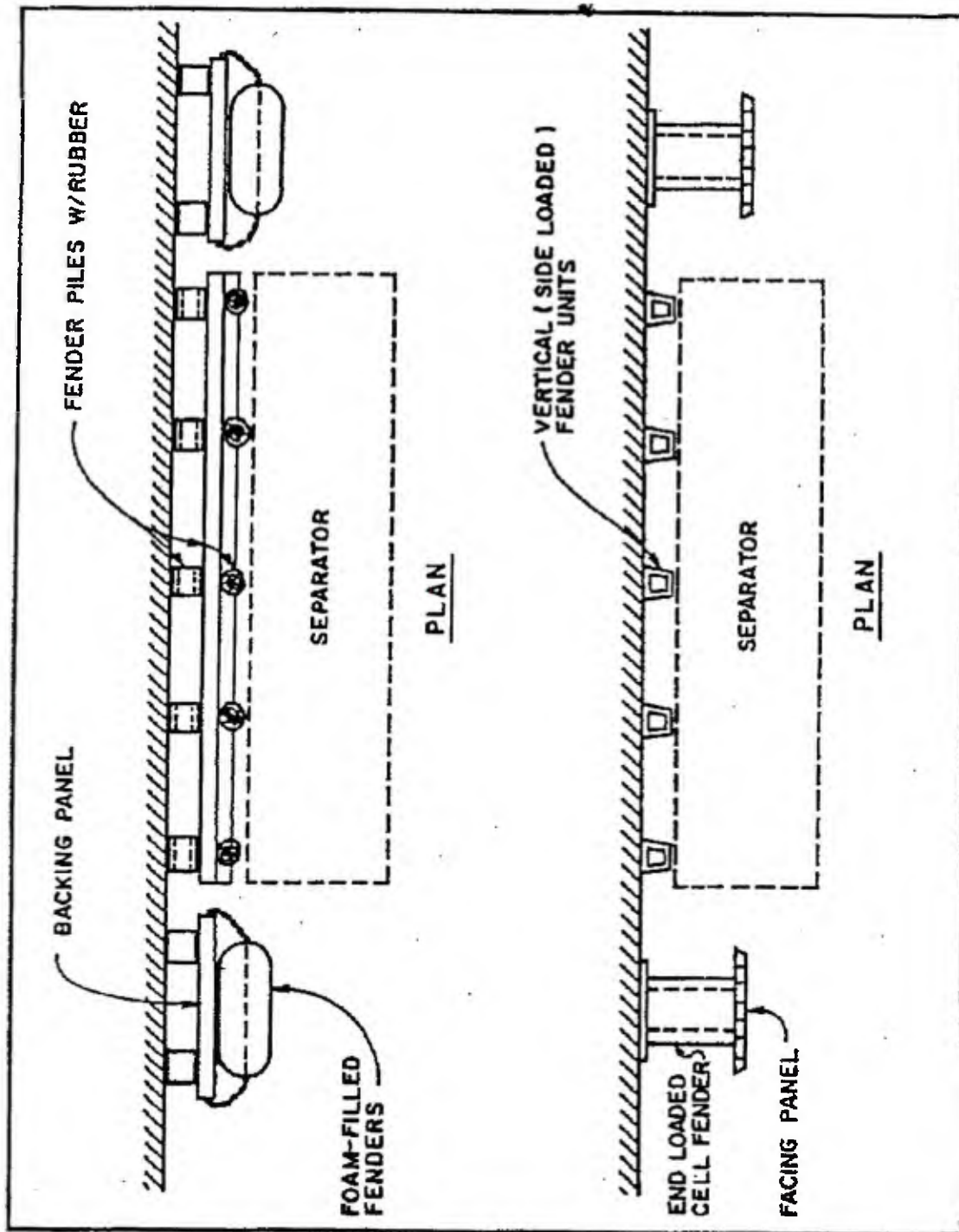


FIGURE 15. COMBINATION SYSTEMS

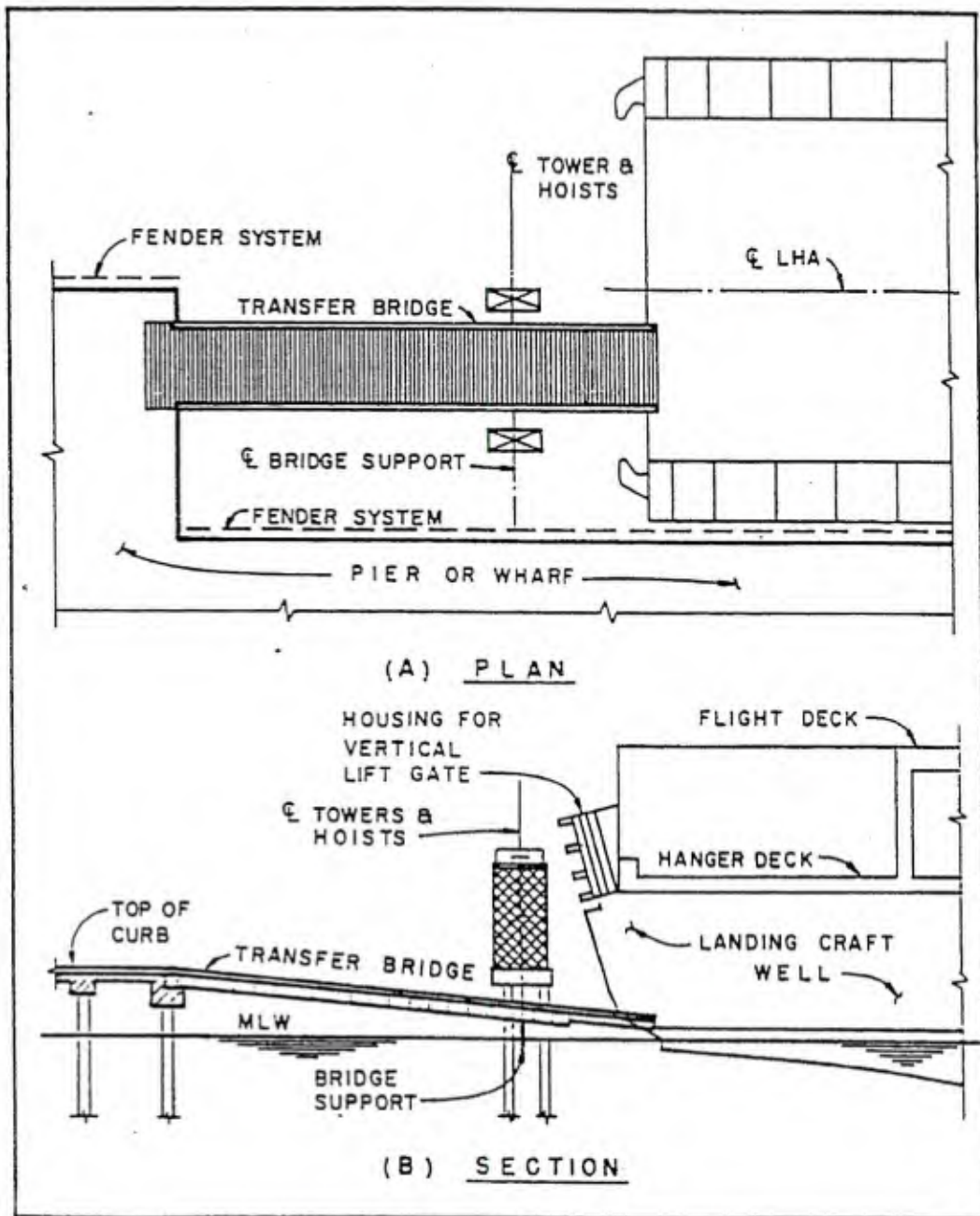


FIGURE 16. TRANSFER BRIDGE FOR LHAs

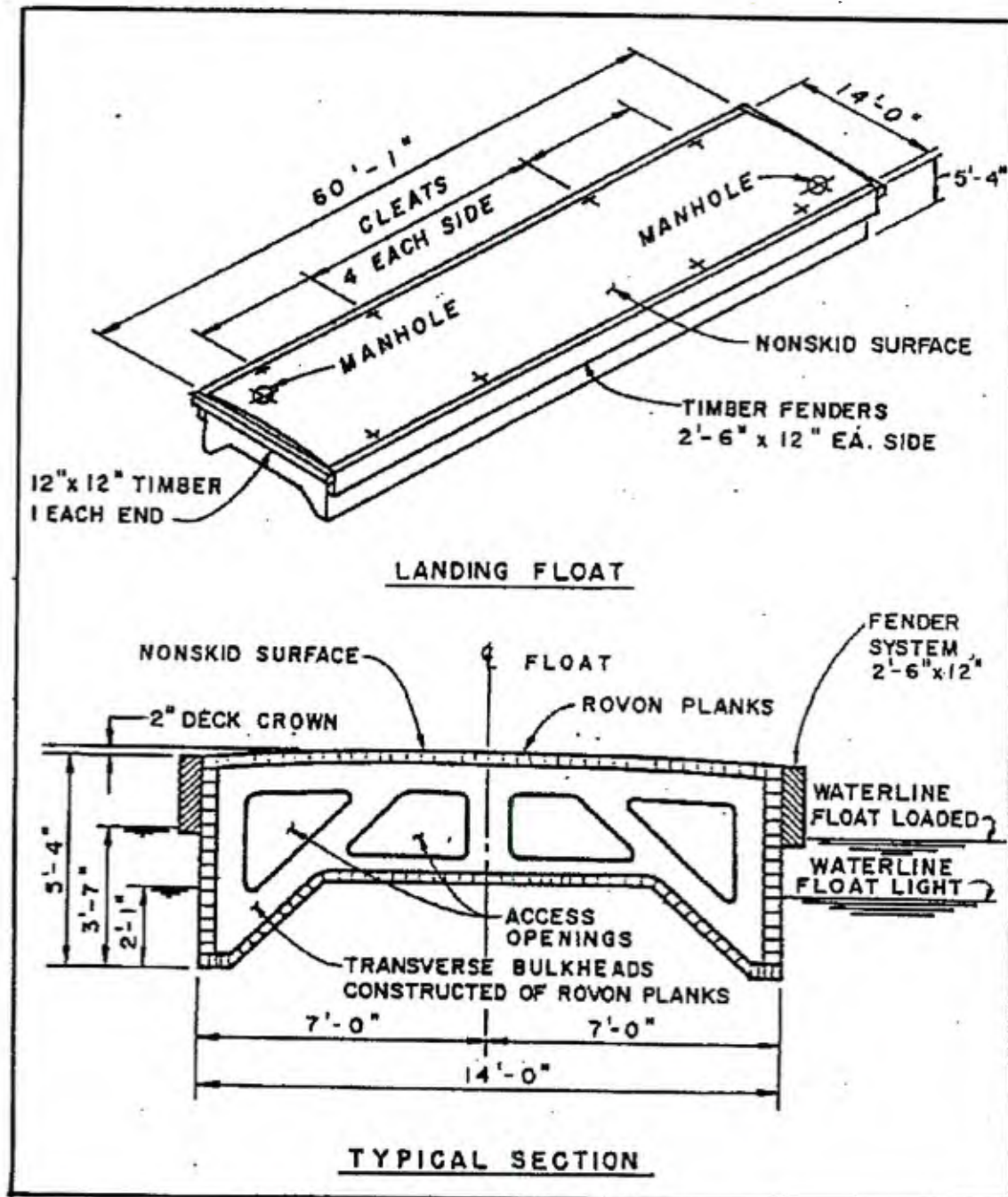


FIGURE 17. REINFORCED PLASTIC LANDING FLOAT

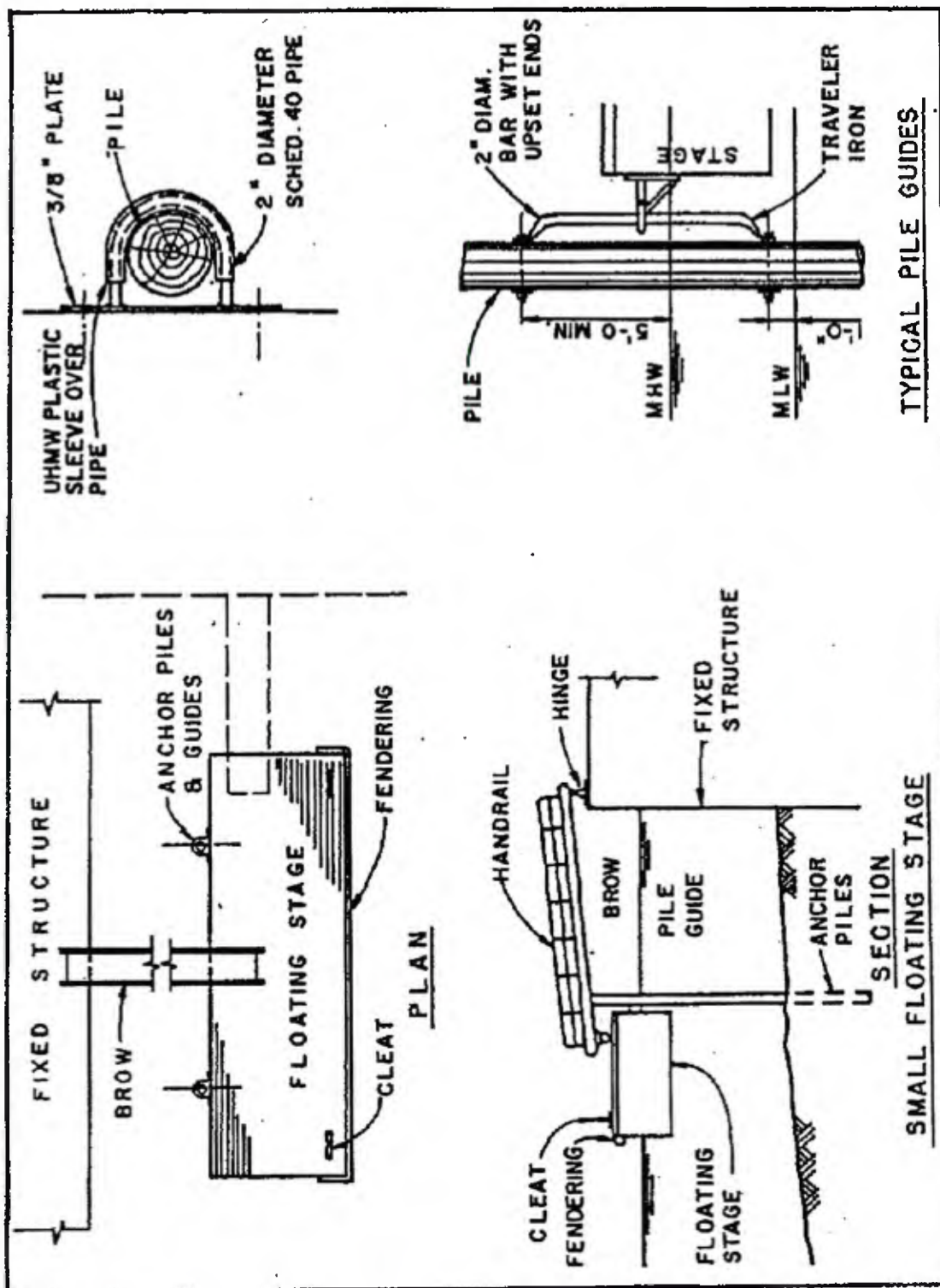


FIGURE 18. BROW / SMALL FLOATING STAGE

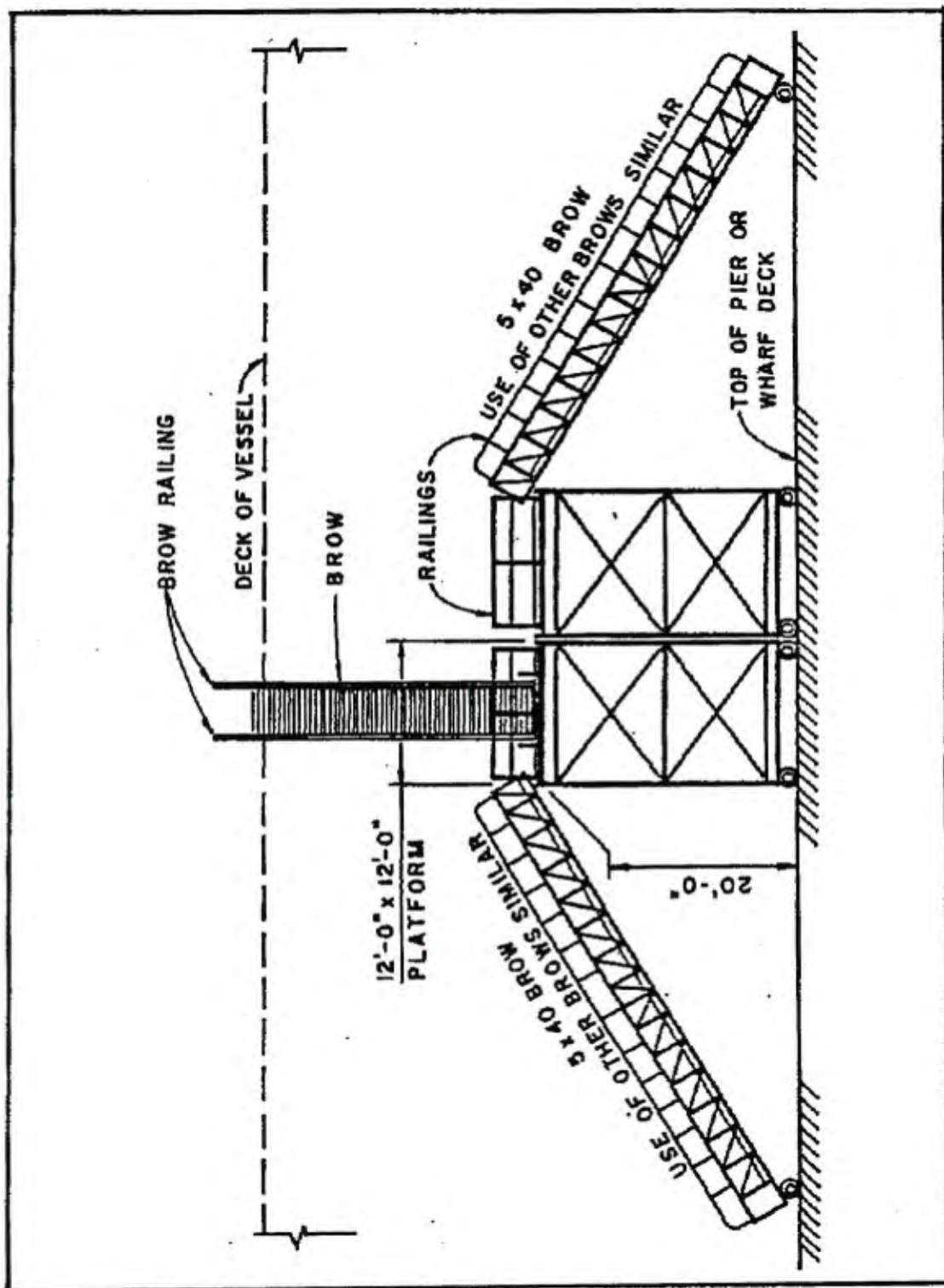


FIGURE 19. BROW PLATFORM FOR LARGE SHIPS

APPENDIX A **MATERIALS PROPERTY DATA FOR WOOD PLASTIC COMPOSITES**

TABLE A-1. Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|---------------|------|---|---|------|-------------|
| Price | | | Competitive with clear and No. 2 shop pine | | |
| Raw Materials | | | Cellulose material makes up 70% of the composite (cross- linked with polyolefin resin materials). No formaldehyde or volatile organics. Cellulose materials that can be used: Hardwoods, softwoods, MDF waste, particle board, plywood waste, cardboard, newspaper, bamboo, field crops. | | |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|--------------------------------------|--|---|-----------------------------|---|----------------------|
| Maximum width | | | 22 in. (could be more) | | |
| Woodworking tolerances | | | ± 0.010 (could be more) | | |
| Recommended Wall Thickness | | | 0.100 to 0.375 in. | | |
| Water Absorption ASTM D1037 | 17.2% (Ponderosa Pine-Crane data) | | 0.7% (24 hr immersion?) | 1.7% (unsanded) 4.3% (sanded) (24 hr immersions) | 0.7% |
| Coefficient of Moisture Expansion | | | | 3% (Long Term Immers. 36" long samples) 1% (Constant high humidity 6" long samples) | |
| Thickness Swell ASTM D1037 | 2.6% (Ponderosa Pine-Crane data) | | 0.2% | | 0.6% |
| Specific Gravity | 0.54 (Doug Fir at 12% moisture) 0.38 (West. White pine 12% moisture) 0.40 (Ponderosa pine at 12% moisture) | | 1.1 | 0.91-0.95 (ASTM D2395) | 1.235 (ASTM D792) |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|--|---|---|----------|--------------------------------------|---------------------------------|
| Hardness ASTM D143 | 460 (Pond. Pine at 12% moisture) 710 (Doug Fir at 12% moisture) 420 (West. White pine 12% moisture) | | 1,288 | 1124 lbs (ASTM D143) | 65 (Shore D - ASTM D2240) |
| Abrasion | | | | 0.01" wear/1000 revs (ASTM D2394) | |
| Static Coefficient of Friction | | | | Dry 0.53 Wet 0.70 (ASTM D2047) | |
| Impact Bending (in) (Height of drop causing complete failure) | 19 (Ponderosa pine at 12% moisture) 31 (Doug Fir at 12% moisture) 23 (West. White pine at 12% moisture) | | | | |
| Work to maximum load (in-lb/in ³) | 8.8 (West. White pine 12% moisture) | | | | |
| Compression Perpendicular to Grain (psi) ASTM D198 | 580 (Ponderosa Pine at 12% moisture) 800 (Doug Fir at 12% moisture) 470 (West. White pine 12% moisture) 238 (White Pine avg) 450 (Doug Fir avg.) | | 2,441 | 1944 ASTM D143 | |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|---|--|---|----------|----------------------|-------------|
| Compression Parallel to Grain (psi) ASTM D198 | 5320 (Ponderosa Pine 12% moisture) | | | | |
| | 7240 (Doug Fir at 12% moisture) | | | | |
| | 3610 (Doug Fir avg) | | | | |
| | 5040 (West white pine 12% moisture) | | | | |
| Shear (psi) ASTM D143 | 2650 (White Pine) | | 2,428 | 1806 ASTM D198 | |
| | 1130 (Ponderosa pine at 12% moisture) | | | | |
| | 1130 (Doug Fir at 12% moisture) | | | | |
| | 922 (Doug Fir avg) | | | | |
| Tensile (psi) ASTM D198 | 1040 (West. White pine 12% moisture) | | | | |
| | 635 (White Pine avg) | | 1,188 | 561 (Para. Perp.) | |
| | 420 (Pond. Pine at 12% moisture, perp.) | 2913 (0% wood) | | | |
| | 20000 (Doug Fir 12% moisture, parallel) | 1933 (40% small chips) | | | |
| | 340 (Doug Fir-12% moisture, perp.) | 1578 (50% small chips) | | | |
| | | 1000 (60% small chips) | | | |
| | | 1330 (40% med. chips) | | | |
| | | 1206 (50% med. chips) | | | |
| | | 921 (60% med. chips) | | | |
| | | 1151 (40% large chips) | | | |
| | | 941 (50% large chips) | | | |
| | | 750 (60% large chips) | | | |
| | | | 1,204 | 854 (Parallel) | |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|--|---------------------------------------|---|----------|------------------|-------------|
| Modulus of Elasticity (ksi) ASTM D790 | 1,290 (Pond Pine at 12% moisture) | 165 (0% wood) | | | |
| | 1,950 (Doug Fir at 12% moisture) | 315 (40% small chips) | | | |
| | 1,613 (Doug Fir avg) | 323 (50% small chips) | | 175 | 621 |
| | 1,460 (West. White pine 12% moisture) | 280 (60% small chips) | 505 | ASTM D4761 | (ASTM D790) |
| | 1,168 (White Pine avg) | 304 (40% med. chips) | | | |
| Modulus of Rupture (psi) | 9400 (Pond. Pine at 12% moisture) | 291 (50% med. chips) | | | |
| | 12,400 (Doug Fir at 12% moisture) | 283 (60% med. chips) | | | |
| | 7540 (Doug Fir-avg) | 269 (40% large chips) | | | |
| | 9700 (West. white pine 12% moisture) | 245 (50% large chips) | | | |
| | 5220 (White Pine average) | 239 (60% large chips) | | | |
| | | 3626 (0% wood) | | | |
| | | 4024 (40% small chips) | | | |
| | | 3742 (50% small chips) | | 1423 | 3260 |
| | | 2950 (60% small chips) | | (ASTM D4761) | (ASTM D790) |
| | | 3386 (40% med. chips) | | | |
| Fastening Nail Withdrawal (lbs/in.) ASTM D1761 Screw Withdrawal (lbs/in.) ASTM D1761 | 51 (Ponderosa Pine- Crane data) | 2958 (50% med. chips) | | | |
| | | 2397 (60% med. chips) | | | |
| | | 3419 (40% large chips) | | | |
| | | 2066 (50% large chips) | | | |
| | | 1776 (60% large chips) | | | |
| | | 28.1 (0% wood) | | | |
| | | 30.8 (40% small chips) | | | |
| | | 31.9 (50% small chips) | 97 | 163 | 70 |
| | | 28.9 (60% small chips) | | (8d common nail) | |
| | | 29.2 (40% med. chips) | | | |
| | | 29.5 (50% med. chips) | | | |
| | | 28.8 (60% med. chips) | | | |
| | | 29.9 (40% large chips) | | | |
| | | 29.4 (50% large chips) | | | |
| | | 22.3 (60% large chips) | 438 | 558 | 670 |
| | | | | (#10 wood screw) | |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|---|--|---|--|---|-------------|
| Thermal Expansion (PPM/°F) ASTM D696 | 2.5 (Ponderosa Pine-Crane data) | | 16 | Width 42.7 Length 19.2 (36" long samples) | |
| Temperature Distortion | | | No distortion to 220F (unloaded) | | |
| Heat Distortion Temperature ASTM D648 | | | 176 F. (Some experimental types up to 190 F.) | | |
| Thermal Conductivity (BTU/hr/sq ft/°F) ASTM C177 | 1.6 - 2.9 (Ponderosa Pine-Crane data) | | 2.03 | 1.75 (BTU-in/hr-ft at 85F) | |
| Fire Ratings (UL Tunnel Test) Ratings: Flame-spread Fuel-contribution Smoke-generation | 100 (Redwood) | | Unmodified, standard (retardant could be added) 46 64 117 | 80 (ASTM E84) | |
| Self Ignition Temperature | | | | 743 F. (ASTM D1929) | |
| Flash Ignition Temperature | | | | 698 F. (ASTM D1929) | |
| Chemical Resistance | | | Paint stripper, hydrogen chloride, uric acid, household cleaner | | |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|---------------------|------|---|---|-----------------------------|-------------|
| UV Resistance | | | Fades after 3000 hrs direct UV exposure. Physical properties are not affected. | | |
| Pest Resistance | | | Superior to regular wood | 9.6 (Termite AWPA E1-72) | |
| Fungal Resistance | | | | No decay (ASTM D1413) | |
| Paint Adhesion | | | Excellent with proper primer or surface preparation. 85-90% topcoat adhesion without priming for flame-treated, sanded surface. | | |
| Adhesives | | | Standard wood adhesives provide good adhesion. Cyanoacrylates especially effective. | | |
| Veneer-Wrapping | | | Yes - with wood veneer or vinyl | | |
| Coloring or Tinting | | | Yes - using standard industry pigments | | |

TABLE A-1 (Continued). Properties of Wood and Wood Composites

| PROPERTIES | WOOD | SOUTHERN PINE/ POLYETHYLENE COMPOSITE | STRANDEX | TREX | TIMBER-TECH |
|---------------|-------------------------------------|---|--|-------------------------|-------------|
| Milling | | | Yes - can be milled, turned, mitered, drilled, tapped, planed, sanded and routed | | |
| Thermoforming | | | No extensive testing to date | | |
| Welding | | | No, but radio-frequency welding with water-based PVA glue may be possible | | |
| Recycling | Various methods | | Yes - can be ground and mixed with virgin Strandex, then extruded | | |
| MSDS | ----- | | Yes - but Strandex sawdust is non-hazardous | | |
| Leaching | No leaching issues for natural wood | | No leaching issues in all EPA constituent categories | Pass (TCLP-EPA 1311) | |

APPENDIX B
NFGS-02458B Timber Piles (June 96)

Supersedes NFGS-0261.

All NFGS are short documents that provide guidelines to prepare contract specifications. The complete text of each NFGS should be reviewed to insure that no guideline needs revision to accommodate engineered wood.

DEPARTMENT OF THE NAVY
NAVAL FACILITIES
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-02458B
30 June 1996

Superseding NFGS-02458A (03/96)

TIMBER PILES

APPENDIX C
NFGS-02461A Wood Marine Piles (March 96)

Supersedes NFGS-02483.

DEPARTMENT OF THE NAVY
NAVAL FACILITIES
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-02461A
31 March 1996

Superseding NFGS-02461
(12/95)

WOOD MARINE PILES

APPENDIX D
NFGS-02398 Pier Timberwork (December 95)

Supersedes NFGS-02491 which itself superseded NFGS-02891.

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-02398
31 December 1995

Replaces NFGS-02491J (03/95)

PIER TIMBERWORK

APPENDIX E
NFGS-05650A Railroad Track and Accessories (March 96)

Supersedes NFGS-02452.

DEPARTMENT OF THE NAVY
NAVAL FACILITIES
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-05650A
31 March 1996

Superseding NFGS-0565012/95)

RAILROAD TRACK AND ACCESSORIES

APPENDIX F
NFGS-06100W Rough Carpentry (September 96)

DEPARTMENT OF THE NAVY
NAVAL FACILITIES
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-06100W
30 September 1996

Superseding NFGS-06100V (06/96)

SECTION
WOODS & PLASTICS SECTION 06100
ROUGH CARPENTRY

APPENDIX G
NFGS-02581 Utility Poles (September 96)

DEPARTMENT OF THE NAVY
NAVAL FACILITIES
1996
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-02581
30 September

Superseding NFGS-16301 (IN PART)

UTILITY POLES



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